CALIBRATION TEST OF ELECTRIC WATER METER

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water meter

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A THESIS

PRESENTED BY

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MECHANICAL ENGINEERING

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T A B L E O F C O N T E N T S .

T A B L E O F C O N T E N T S (continued)

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The object of this report is the investigation of a new type of water meter.

The meter consists of a combination of three different parts, namely, the part inserted into the pipe line from which the static and dynamic heads are obtained, the manometer in which the dynamic head is measured, and the electrical apparatus used in measuring the head produced. The meter was designed for use in measuring the flow of water in a three inch standard pipe.

The part of the meter which is inserted into the pipe consists of a multi-opening averaging pitot tube, which is constructed as shown in plate 14, with two tubes, AA, 3.06 inches in length, 1-4 inch outside diameter, having ten 1-16" holes drilled as shown. These tubes extend from a solid cylindrical part, B, which is 5-8 of an inch in diameter and 2 3-4 inches long, through which are two holes bored lengthwise, corresponding to the bore of the tubes extending from it. The other end of this cylindrical piece is arranged with separate stop cocks, CC, for each tube

. and threaded for connection to pipe union. This part is fitted into a stuffing box, D, which is arranged so that it can be clamped securely to the inner part by means of a screw, E. The stuffing box is threaded to fit in connections for 3-4 inch pipe. This is screwed into a 3-4 inch hole in the pipe and the tubes AA, are turned so that the holes in the dynamic side face upstream and those in the static side face downstream. The tubes reach to the other side of the pipe and the stuffing box is screwed into the pipe so that it just reaches to the inner side of the pipe. The clamping screw is then tightened to hold it in place.

The manometer, or part in which the dynamic head is measured, is shown in plates 15 and 16. The connection with the static and dynamic sides of the Pitot tube are made at A and B respectively. The valve C closes the connection between the two sides and causes the mercury column to rise in the body of the manometer. The pipe G, 1-4 inch standard,

connects the static pressure with the chamber E, which is filled with oil. The pipe D, 1-4 inch standard, connects the dynamic pressure with the chamber F, which is filled with mercury to the level O. The oil in E overflows into K, and comes in contact with the surface of the mercury. The difference in pressure between F and E causes the mercury to rise in K, thus acting as a manometer. The mercury level is adjusted so that it just touches the end of the longest of the 41 contacts, L, when the slightest head is obtained above the zero. These contacts are attached to resistances which vary a definite amount for each wire. The resistance is in the form of coils wound around spools which are held between the non-conducting discs, N and P. The wires vary in length uniformly through a range of $\frac{21}{64}$ of an inch, giving a different resistance for the very small difference in head of .0082 of an inch of mercury. A rubber ring, R, is arranged so that each wire passes through it. This holds the wires apart and prevents short circuiting

between the wires themselves and also between the wires and the wall S. The contacts, resistances, etc., are connected together in one piece which is suspended, as shown in plate 15, by a screw, having fine threads, which passes through the plug T in the top of the meter The meter is grounded. Under these conditions no current flows until the contacts, L, come in contact with the mercury in the chamber F. The amperes depend upon the resistance in the circuit, which depends upon the number of contacts touching the mercury. The latter depends upon the height of the mercury in chamber F, which depends upon the difference between combined static and dynamic head and the static head. This difference in head bears a direct relation to the velocity or flow of water in the pipe. The body of the meter is made of cast iron, of shape as shown. The cover is bolted on and is provided with a projecting ring which fits into a corresponding groove in the body itself. A gasket insures an air tight joint between cover and body of meter. A plug, U, is

provided for draining chamber E, and one also as V, to drain the chamber K. The plug W, is used to draw out enough mercury to adjust the level for the zero reading.

The electrical apparatus used in measuring the current consists of an A. C. Voltmeter (0-60), a wattmeter, transformer, a coil for varying the resistance of the current, and an A. C. Ammeter (0-2). Direct current cannot be used because of the plating effect of the mercury upon the contacts. The diagram of the electrical connections is shown in plate 17. When the relation between the amperes and flow are found, the flow in the pipe can be found by referring to the ammeter. The wattmeter is used for continuous readings.

The scheme of connections used in the final tests is shown in plate 17. The meter was attached to a three inch line containing a Venturi meter with a mercury manometer reading in inches of mercury. The pitot tube was placed in the side of the horizontal

run of pipe so that the flow was measured after passing the Venturi meter. A gate valve was provided in the vertical pipe as shown, and a needle valve leading to a Pelton wheel was used in regulating the flow through the pipe. The meter was grounded through the 3" pipe, alternating current was used from a rotary converter at 75 volts. This was reduced to 37.5 volts at the transformer. One line from the transformer was grounded and the ammeter, and resistance coil was connected in the other. The resistance coil was used in regulating the current through the meter. This line was attached to the meter

The water was obtained from a well in the hydraulic laboratory, and was discharged into this same well. The water was supplied to the line by a multi-stage Worthington centrifugal pump, direct connected to a 40 H. P. Kerr turbine situated in the engine room. The suction to this pump was carried overhead from the well and an air pocket was formed in this line. This line was primed by a line from

the city water mains and an air cock was provided at its hightest point for the escape of the air. Alternating current was obtained from a rotary converter, in the Dynamo laboratory, receiving direct current from the mains at 110 volts and delivering 75 volts alternating current. This was transformed down to 37.5 volts at the meter.

The electrical contacts were tested in order to find out the ammeter reading for each electrical contact, and to determine the distance between the ends of each two contacts. This was done by connecting each contact separately, in series with the circuit and taking the ammeter reading for each. The short circuit ammeter reading was adjusted to .97 by changing the resistance and the test was made with the line voltage contact at 37.5. The ammeter reading for each contact was tabulated and the difference in head between the longest (No.1) contact and each successive one was tabulated. The results of this test are shown in table 1 and from this data the

curves in plates 1 and 2 were drawn, showing the ammeter reading for each contact, and for each corresponding variation in dynamic head.

Numerous preliminary tests were made upon the meter and several adjustments and changes were made before consistent results were obtained. The meter was at first attached to the 3" boiler feed line, which was supplied with a Venturi meter having an indicating and recording apparatus. The test was made with the other apparatus arranged as shown in plate 17. The velocity was low in this line and the flow variable. The variation in the velocity in the line, due to the pulsating effect of the reciprocating boiler feed pumps, caused the ammeter reading to be continually changing. This made it hard to get accurate ammeter readings. The meter was then changed to the position on the line as shown in plate 17. The flow in this line from a centrifugal pump, was steady and the velocity could be regulated as desired. The results of runs on this line showed

that something was wrong.It was found that the rubber ring, shown as R, in plate 15, had slipped down and some of the contacts had touched each other, thereby causing an error in the results obtained, This ring was placed as it should have been and more consistent results were obtained, but it was found that in some way mercury had gotten into the lower part of the chamber E and water had gotten in between the mercury and oil in K. The meter was cleaned and dried and the mercury was placed in chamber F to a height a little above the zero level. Oil was then poured into E and K until the meter was filled to the cover with oil. The top was bolted on, and when the mercury level was adjusted properly, the readings were consistent. The electrical contacts and coils were at first held in a stationary position between the cover of the meter and the upper edge of wall S. This was changed by attaching this part to a screw as described before and allowing space of about 1-8 of an inch for the contacts to be raised or lowered by

turning the screw at the top. This permitted the contacts to be adjusted to suit the level of the mercury in the meter. A mercury manometer was connected to the meter at the points A and B after the plugs H and J, plate 15, had been removed. This allowed the head to be read directly, but as trouble resulted in removing all the air from the system, and also as the variations in head were so very small, this arrangement was not used. The final tests were made after all of these changes had been made.

In starting the test a number of things had to be considered. The suction to the pump was carefully primed and the centrifugal pump started. The water was allowed to flow for some time through the pipe before readings were taken because of the great quantity of air in the pipe at first. After the air had been driven out of the line, the air was let out of the pockets existing in the connections to the Venturi meter and the electric meter.

By opening the valve C, plate 15, between the static and dynamic sides of the meter, a flow of water due to the difference in pressure drives out the air from these connections. After the air had been driven from the connections, the ammeter and other electrical connections wewe arranged as in plate 17. The rotary converter was started and the meter was ready for adjustment. The valve C was closed and the meter short circuited by allowing all of the contacts to touch the mercury and the ammeter reading was adjusted to .97 by varying the resistance R. The voltage was read across the transformer terminals to be 37.5. The mercury and contacts were then adjusted to zero. This was accomplished by closing the needle valve, thereby stopping the flow, and adjusting the level of of the contacts to their highest position and then drawing out enough mercury from plug W to bring the ammeter reading to zero. The level of the contacts was then adjusted, by means of the screw at the top, so that the slightest rise in the mercury caused a

reading of the ammeter corresponding to that of the lowest contact. The meter was then ready for use. Runs were then made, starting with no flow and increasing to the highest and back again, varying the flow just enough to give every change of ammeter reading. The corresponding head on Venturi manometer was recorded. The voltage across the terminals of the transformer was read at intervals to note any variation in the voltage in the supply line. The results of these runs are shown in the tables 3, 4, 5, 6, 7.

From the data obtained in the different parts of the tests the results were tabulated and curves drawn. Table 1 gives the data obtained on the electrical contacts. These results were used in making the curves shown in plates 1 and 2. Plate 1 shows the ammeter reading for each contact, and plate 2 shows the corresponding difference in head for each ammeter reading. Table 2 contains the flow Q, in cubic feet per second, for each variation of one inch of mercury

in the head h, as indicated by the Venturi meter. The value of Q was calculated from the formula for this meter, which is $Q = .069 \sqrt{h}$. from this data the flow curve for the Venturi meter was made as shown in plate 3. Tables 3, 4, 5, 6, and 7 were made from the data obtained in the final runs upon the meter. The ammeter and Venturi head readings were taken in the tests and tabulated.

The pitot dynamic head in inches of mercury was obtained from the dynamic head curve in plate 2. From this data the flow in cubic feet per second was found from each meter and the coefficient for each reading obtained by dividing the flow as found by the electric meter by that found from the Venturi meter. The average of these runs was found. Plates 4, 5, 6, 7 and 8 show the ammeter reading for each variation in flow for each run. The flow was taken as that indicated by the Venturi meter. Plates 9, 10, 11, 12 and 13 show the values for the coefficient for each variation in flow obtained from the Venturi

meter for each run. The mean value of the coefficient is shown in each case.

In obtaining the results shown in the tables from the original data, a few simple formulas were required. These formulas are those found by expermient to suit the various uses. In obtaining the flow in cubic feet per second as indicated by the pitot tube, the theoretical formula was used. This formula has been found to meet the conditions found in experiment. The ammeter reading gives the head, by referring to plate 2, and the corresponding velocity is obtained from the formula $V = \sqrt{2gh}$ where V is the velocity in feet per second, g is the acceleration due to gravity and h is the average dynamic head in feet of water. The multi-opening averaging pitot tube was assumed to give the average head. This tube has been described above. The ten holes receiving the impact of the moving water are spaced across the pipe as follows: The area of the pipe is divided into five equal areas and a circle is drawn in each at a position

such that each area is divided in half. The impact on each of these circles gives the average for each area and the head corresponding to the average velocity of flow across the area of the pipe is produced by averaging these impacts. The formula for finding the position of each of these holes is

$R = r\sqrt{\frac{2a-1}{N}}$ where

R = distance from the center of the pipe to each position of pitot opening,

a = the number of the position from center of pipe

N = the total number of positions taken across pipe

r = radius of pipe in inches.

In this case, r = 1-2 x 3.06" 1.53" and N =10.

$R = 1.53\sqrt{\frac{1}{10}}$ = .48"

$R = 1.53\sqrt{\frac{3}{10}}$ = .83"

$R = 1.53\sqrt{\frac{5}{10}}$ = 1.07" etc.

Knowing the value of the head, h and calculating the value of the velocity V, in the pipe, the flow in cubic feet per second is found by the simple multipli-

cation of the velocity by the area of the pipe which makes $Q = \frac{\pi}{4} d^2 V = \frac{\pi}{4} d^2 \sqrt{2gh}$,

g = 32.2   d = 3.06" for standard 3" pipe.

The reslute obtained in the various parts of the test show that the meter is very sensitive. The curves in plates 1 and 2 show that the resistances attached to the contacts give a curve for amperes resembling a parabola. This curve is very smooth with the exception of one point between the readings .87 and .89 amperes. The calibration curve for the Venturi meter is drawn from a mathematical formula and represents a smooth parabola. The accuracy of the meter is known to be good. Plates 4, 5, 6, 7 and 8 showing the relation between the flow and ammeter reading show that there is a slight variation in the reading of the ammeter for an increasing flow and a decreasing flow. The decreasing flow in four out of the five cases shows a high ammeter reading for a given velocity in pipe. This is to be expected, owing to the capillary action of the walls from the upper

surface of the mercury. The average of these five curves is about the same, showing a reading of ammeter for each contact. The variations in these curves are also affected by slight changes in the line voltage. This was noted in table 6 which shows in curve on plate 7. The voltage increased near the end of the run, and the ammeter reading did not return to zero when the flow was stopped. This was unavoidable and it is fair to assume that the average of the results is correct because the test was run at the ordinary voltage carried and lower voltages no doubt existed during a part of these runs. The curves shown in plates 9, 10, 11, 12 and 13 show the relation between the coefficient and the flow. These curves show an increased coefficient for the decreasing flow. This set of curves is very irregular when compared to the ampere flow curves. The average coefficient for all of the runs is 1.25. Judging from the two sets of curves, the Venturi meter is less sensitive than the electric meter.

The following conclusions may be drawn with regard to the conditions influencing the accuracy and dependability of the electric meter as shown by this test:

1. The voltage must be constant in order to get constant ammeter readings for different rates of flow.

2. The mercury zero level must be accurately adjusted and its upper surface must be clean and free from dirt.

3. All air must be driven from the connections. The meter is therefore expected to give better service on lines which are constantly filled with water than on lines that may sometimes be drained and filled with air.

4. The meter may be depended upon to give consistent results.

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clumsy, difficult to manipulate, fragile and altogether unsuited to high velocity measurement.

(b) The Gebhardt type is light, compact, very portable, convenient and easy to manipulate. Very accurate up to 6000 feet per minute but beyond this its accuracy is problematical.

(c) The U. S. No. 1 tube is less convenient and less portable than the Bebhardt. It is much simpler in construction and will stand more abuse. Does not require as much care in manipulation as the other two types. Accurate to 250000 feet per minute.

(d) The exact formula is more accurate, especially at high velocities, than the one usually used.

(e) Present data on friction of air in pipe are largely in error. Discussion by D. W. Taylor page 1168-1172. Attention called to importance of proper static openings. Impact upon static openings give too high reading. 37 Pages, 10

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Table 1

DATA ON ELECTRIC[illegible]

Short Circuit Amperage = .97.

Difference in length between contacts No. 1 and [illegible] 41 is 41/64 of an inch = .328."

1/40 X 21/64 = .0082.

Contact No.	Amperes.	Difference in Length in Inches	Contact No.	Amperes	Difference in [illegible]
0	0	[illegible]	[illegible]	.755	.1[illegible]
1	.10	.0082	[illegible]	[illegible]	.1[illegible]
2	.20	.0164	23	.705	[illegible]
3	.25	.025[illegible]	24	[illegible]	.1[illegible]
4	.30	.0330	[illegible]	[illegible]	[illegible]
5	.35	.041	26	[illegible]	[illegible]
6	.38	.049	[illegible]	[illegible]	[illegible]
7	[illegible]	.057	28	[illegible]	[illegible]
8	.415	.06[illegible]	[illegible]	[illegible]	[illegible]
9	.47	.074	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	31	[illegible]	[illegible]
11	[illegible]	.090	[illegible]	[illegible]	[illegible]
[illegible]	.55	[illegible]	[illegible]	[illegible]	[illegible]
13	.57	[illegible]	[illegible]	[illegible]	[illegible]
14	.59	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	.62	.123	[illegible]	[illegible] 5	[illegible]
16	.65	.131	[illegible]	[illegible]	[illegible]
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	[illegible]	[illegible]	[illegible]	[illegible]65	[illegible]
19	.71	.153	[illegible]	[illegible]	[illegible]
20	.75	.164	40	[illegible]	[illegible]
			41	.97	[illegible]

Table II.

Data for Venturi Flow Curve.

Q = flow in Cubic Feet per Second.

$= .069\sqrt{h}$, where h = head in inches of Mercury.

H	Q	H	Q	H	Q	H	Q
0	0	5	.154	10	.218	15	[illegible]
1	.069	6	.169	11	.229	16	[illegible]
2	.0976	7	.1825	12	.239	17	
3	.1195	8	.195	13	.249	18	
4	.138	9	.207	14	.258	19	

Table III

Amperes	Venturi Head In Inches of Mercury	Pitot Dynamic Head in Inches of Mercury	Flow in Cubic Feet per Second From Venturi	Flow in Cubic Feet per Second From Pitot	Coefficient	Amperes	Venturi Head In Inches of Mercury	Pitot Dynamic Head in Inches of Mercury	Flow in Cubic Feet per Second From Venturi	Flow in Cubic Feet per Second From Pitot	Coefficient
0	0	0	0	0		.81	6.80	[illegible]	.1795	[illegible]	[illegible]
.1	.2	.0085	.025	.0395	1.58	.83	6.35	.199	.173	.194	[illegible]
.2	.45	.0164	.0455	.0557	1.22	.81	6.00	.191	.169	[illegible]	[illegible]
.23	.5	.0225	.0175	.065	1.77	.79	4.95	.187	.153	[illegible]	[illegible]
.27	.55	.0290	.050	.074	1.48	.73	4.70	.184	.149	.1765	[illegible]
.30	.60	.033	.0525	.079	1.51	.70	4.40	.1535	.1445	.1705	[illegible]
.34	.80	.039	.0625	.086	1.375	.68	[illegible]	.1165	.141	.1665	[illegible]
.37	1.10	.046	.0745	.0935	1.255	.66	[illegible]	[illegible]	.1375	[illegible]	[illegible]
.40	1.20	.0525	.0775	.1000	1.29	.64	3.90	.158	.1360	.157	1.15
.43	1.55	.060	.0880	.1067	1.21	.62	3.80	.153	.134	[illegible]	[illegible]
.47	1.80	.074	.095	.1185	1.25	.60	3.50	.1175	[illegible]	.149	[illegible]
.49	2.25	.080	.104	.1237	1.19	.58	3.30	[illegible]	[illegible]	.1145	1.175
.51	2.30	.085	.105	.1270	1.21	.56	3.15	[illegible]	[illegible]	[illegible]	[illegible]
.53	2.45	.0925	[illegible]	[illegible]	1.22	.54	[illegible]	.0955	.118	[illegible]	[illegible]
.55	2.60	.099	.110	.1373	1.22	.51	[illegible]	[illegible]	.114	[illegible]	1.11
.57	2.80	[illegible]	.116	[illegible]	1.230	.40	2.50	[illegible]	.110	[illegible]	[illegible]
.59	3.00	.115	.120	.1480	1.235	.47	2.30	[illegible]	[illegible]	[illegible]	[illegible]
.60	3.50	.1175	.129	.1490	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
.62	3.75	[illegible]	.133	.1530	1.15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
.64	4.00	.128	.1375	[illegible]	1.14	[illegible]	[illegible]	.0505	.090	[illegible]	[illegible]
.66	4.15	[illegible]	[illegible]	[illegible]	1.158	[illegible]	[illegible]	[illegible]	[illegible]	.0875	[illegible]
.69	[illegible]	.150	[illegible]	[illegible]	1.10	[illegible]	[illegible]	.0375	[illegible]	[illegible]	[illegible]
.71	4.30	.156	[illegible]	[illegible]	1.205	.30	[illegible]	.037	[illegible]	[illegible]	[illegible]
.74	4.40	.168	.1445	.1785	1.235	.25	.75	.025	.060	.069	[illegible]
.78	4.50	.180	.1460	.185	1.267	.20	.55	.0164	.050	[illegible]	[illegible]
.81	4.90	.194	[illegible]	[illegible]	1.262	.15	.40	.0125	[illegible]	[illegible]	1.145
.83	[illegible]	.199	.169	.1942	1.15	.10	[illegible]	.0082	.025	[illegible]	[illegible]
.87	7.15	.217	.184	.203	1.105	[illegible]	0	0	0	0	
.88	7.55	.220	.1895	.2045	1.08						
.86	7.10	.213	.183	.2015	1.10						

Ave. Coef = 1.198

Table IV.

Amperes	Venturi Head In Inches of Mercury	Pitot Dynamic Head in Inches of Mercury	Flow In Cubic Feet Per Second From Venturi	Flow In Cubic Feet Per Second From Pitot	Co-efficient
.85	6.70	.207	.178	.198	1.112
.89	8.70	.258	.203	.2215	1.094
.85	6.70	.207	.178	.198	1.112
.83	6.40	.196	.174	.194	1.12
.81	5.30	.194	.1585	.192	1.21
.79	5.10	.187	.155	.188	1.212
.77	4.65	.1775	.153	.184	1.20
.74	4.60	.168	.1475	.1785	1.21
.71	4.55	.156	.147	.172	1.17
.69	4.40	.150	.1445	.168	1.16
.66	4.10	.1375	.139	.162	1.168
.62	4.00	.123	.138	.153	1.11
.60	3.80	.1175	.134	.149	1.112
.58	3.50	.111	.129	.1455	1.125
.56	3.40	.103	.1275	.140	1.10
.55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Amperes	Venturi Head in Inches of Mercury	Pitot Head in Inches of Mercury	Flow In Cubic Feet Per Second From Venturi	Flow In Cubic Feet Per Second From Pitot	Co-efficient
0	0	0	0	0	
.10	.20	.0082	.025	.0395	1.58
.15	.40	.0125	.0425	.0487	1.145
.20	.60	.0194	.0525	.0557	1.06
.25	.80	.025	.0625	.069	1.105
.30	1.00	.033	.069	.079	1.145
.33	1.10	.0275	.0745	.0845	1.135
.36	1.20	.043	.0865	.0903	1.045
.40	1.75	.0525	.0925	.100	1.08
.42	1.95	.057	.0975	.104	1.065
.45	2.20	.069	.1025	.114	1.11
[illegible]	[illegible]	[illegible]	.110	[illegible]	[illegible]

Ave Coef = 1.126

Table IV.

Amperes	Venturi Head In Inches of Mercury	Pitot Dynamic Head in Inches of Mercury	Flow In Cubic Feet Per Second From Venturi	Flow In Cubic Feet Per Second From Pitot	Coefficient	Amperes	Venturi Head in Inches of Mercury	Pitot Head in Inches of Mercury	Flow In Cubic Feet Per Second From Venturi	Flow In Cubic Feet Per Second From Pitot	Coefficient
0	0	0	0	0		.83	6.35	.199	.173	.1942	1.12
.1	.40	.0082	.0425	.0395	.932	.81	5.90	.194	.167	.192	1.15
.2	.55	.0164	.050	.0557	1.11	.79	5.00	.187	.154	.188	1.22
.23	.65	.0225	.0645	.065	1.01	.72	1.60	.160	.1475	.1745	1.18
.27	1.00	.029	.069	.074	1.072	.69	1.35	.150	.143	.168	1.172
.29	1.10	.032	.0745	.078	1.05	.68	1.20	.1465	.141	.1665	1.18
.32	1.30	.0362	.080	.083	1.04	.66	1.00	.1375	.138	.162	1.105
.35	1.45	.041	.0855	.088	1.03	.64	3.90	.128	.136	.157	1.155
.39	1.85	.051	.0955	.0983	1.03	.62	3.70	.123	.1325	.153	1.153
.42	2.10	.057	.100	.104	1.04	.60	3.45	.1175	.128	.149	1.16
.44	2.20	.0645	.1025	.111	1.08	.58	3.45	.1105	.128	.1445	1.17
.47	2.35	.074	.106	.1185	1.12	.55	3.00	.099	.1195	.137	1.147
.49	2.60	.080	.112	.1237	1.10	.52	2.70	.0885	.114	.1297	1.14
.51	2.80	.085	.116	.127	1.096	.50	2.55	.082	.111	.1247	1.12
.53	3.00	.0925	.120	.1327	1.108	.48	2.50	.0785	.110	.122	1.11
.56	3.10	.103	.1275	.140	1.10	.45	2.20	.069	.1025	.114	1.11
.58	3.50	.111	.129	.1455	1.125	.42	1.95	.057	.0975	.104	1.065
.60	3.80	.1175	.134	.149	1.112	.40	1.75	.0525	.0925	.100	1.09
.62	1.00	.123	.138	.153	1.11	.36	1.50	.043	.0865	.0993	1.145
.66	1.10	.1375	.139	.162	1.168	.33	1.10	.0375	.0745	.0845	1.135
.69	4.40	.150	.1445	.168	1.16	.30	1.00	.033	.069	.079	1.145
.71	4.55	.156	.147	.172	1.17	.25	.80	.025	.0625	.069	1.105
.74	1.60	.168	.1475	.1785	1.21	.20	.60	.0164	.0525	.0557	1.06
.77	1.95	.1775	.153	.184	1.20	.15	.40	.0125	.0425	.0487	1.145
.79	5.10	.187	.155	.188	1.212	.10	.20	.0082	.025	.0395	1.58
.81	5.30	.191	.1585	.192	1.21	0	0	0	0	0	
.83	6.40	.199	.174	.1942	1.12						
.85	6.70	.207	.178	.198	1.112		Ave	Coef	=	1.12	
.89	8.70	.258	.203	.2215	1.094						
.85	6.70	.207	.178	.198	1.112						

Table V.

Amperes	Venturi Head	Pitot Dynamic	Flow In Cubic		Coefficient	Amperes	Venturi Head	Pitot Dynamic	Flow In Cubic		Coefficient
.89	7.00	.298	.1825	.2215	1.215						
.88	5.40	.246	.160	.216	1.35						
.85	5.00	.207	.154	.198	1.285		VAC	Coef	-	1.226	
.84	4.60	.205	.1475	.197	1.34						
.82	4.50	.197	.146	.194	1.325						
.80	4.40	.191	.1445	.190	1.315	0	0	0	0	0	
.78	4.40	.180	.1445	.185	1.28	.10	.20	.0082	.025	.0365	
.76	4.20	.175	.141	.182	1.29	.20	.40	.0164	.0425	.0557	1.28
.74	4.00	.168	.138	.1785	1.26	.25	.45	.025	.0455	.098	1.31
.72	4.00	.160	.138	.1745	1.265	.30	.60	.033	.0525	.079	1.51
.69	3.80	.150	.134	.168	1.25	.35	.90	.041	.0665	.088	1.50
.67	3.60	.142	.131	.164	1.25	.40	1.10	.0525	.0745	.100	1.32
.65	3.46	.131	.128	.158	1.235	.45	1.40	.069	.0835	.114	1.34
.62	3.30	.123	.125	.153	1.22	.48	1.60	.0785	.099	.122	1.36
.60	3.30	.1175	.125	.149	1.19	.50	1.85	.082	.0955	.112	1.37
.58	3.05	.1105	.121	.1445	1.195	.55	2.30	.103	.105	.140	1.33
.55	2.85	.099	.1165	.137	1.175	.60	2.70	.1175	.114	.149	1.30
.52	2.60	.0885	.110	.1297	1.18	.62	3.10	.123	.122	.163	1.26

Table V.

Amperes	Venturi Head in Inches of Mercury	Pitot Dynamic Head in Inches of Mercury	Flow In Cubic Feet Per Second From Venturi	Flow In Cubic Feet Per Second From Pitot	Coefficient	Amperes	Venturi Head in Inches of Mercury	Pitot Dynamic Head in Inches of Mercury	Flow In Cubic Feet Per Second From Venturi	Flow In Cubic Feet Per Second From Pitot	Coefficient
0	0	0	0	0		.92	8.10	.270	.196	.2265	1.16
.1	.2	.0082	.025	.0395	1.58	.89	6.65	.258	.1775	.2215	1.25
.2	.4	.0164	.0425	.0557	1.31	.88	5.25	.246	.1575	.216	1.37
.25	.7	.025	.0575	.069	1.20	.86	4.90	.213	.152	.2015	1.33
.30	.85	.033	.0645	.079	1.22	.85	4.70	.207	.149	.198	1.33
.33	.11	.0375	.0745	.0845	1.135	.82	4.40	.197	.1415	.194	1.34
.36	1.3	.043	.080	.0903	1.13	.80	4.30	.191	.1425	.190	1.33
.40	1.6	.0525	.089	.100	1.125	.78	4.10	.180	.139	.185	1.73
.42	1.75	.057	.0925	.104	1.125	.76	4.00	.175	.138	.182	1.71
.45	1.95	.069	.0975	.114	1.165	.74	4.00	.168	.138	.1785	1.29
.48	2.10	.0785	.100	.122	1.22	.72	3.80	.160	.134	.1745	1.30
.50	2.30	.082	.105	.1247	1.07	.67	3.40	.142	.1275	.164	1.29
.52	2.50	.0885	.110	.1297	1.18	.62	3.10	.123	.122	.153	1.25
.55	2.85	.099	.1165	.137	1.175	.60	2.70	.1175	.114	.119	1.30
.58	3.05	.1105	.121	.1445	1.195	.56	2.30	.103	.105	.140	1.33
.60	3.30	**.1175**	.125	.149	1.19	.50	1.85	.082	.0955	.112	1.37
.62	3.30	.123	.125	.153	1.22	.48	1.60	.0785	.089	.122	1.36
.65	3.45	.131	.126	1158	1.235	.45	1.40	.069	.0835	.114	1.34
.67	3.60	.142	.131	.164	1.25	.40	1.10	.0525	.0745	.100	1.32
.69	3.80	.150	.134	.168	1.25	.35	.90	.041	.0665	.088	1.50
.72	4.00	.160	.138	.1745	1.265	.30	.60	.033	.0525	.079	1.51
.74	4.00	.168	.138	.1785	1.29	.25	.45	.025	.0455	.068	1.31
.76	4.20	.175	.141	.182	1.29	.20	.40	.0164	.0425	.0557	1.58
.78	4.40	.180	.1445	.185	1.28	.10	.20	.0082	.025	.0395	
.80	4.40	.191	.1445	.190	1.315	0	0	0	0	0	
.82	4.50	.197	.146	.194	1.325						
.84	4.60	.205	.1475	.197	1.34		Ave	Coef	-	1.22	
85	5.00	.207	.154	.198	1.285						
88	5.40	.246	.160	.216	1.35						
.89	7.00	.258	.1825	.2215	1.215						

Table VI.

Amperes	Venturi Head in	Pitot Dynamic Head	Flow In Cubic Feet Per		Coefficient
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
58	2.75	.1105	.115	.1445	1.255
60	2.90	.1175	.118	.149	1.26
62	3.10	.123	.122	.153	1.255
65	3.40	.131	.1275	.158	1.24
69	3.60	.150	.131	.168	1.281
72	3.85	.160	.135	.1745	1.292
74	4.00	.168	.138	.1785	1.292
79	4.40	.187	.3445	.188	1.30
82	4.60	.197	.1475	.194	1.315
84	4.70	.205	.149	.197	1.32
89	5.10	.258	.155	.2215	1.43
90	6.30	.262	.1725	.223	1.29
92	6.45	.270	.175	.227	1.297
90	6.30	.262	.1725	.223	1.29
89	6.10	.258	.170	.2215	1.305
86	4.65	.213	.1585	.201	1.265

Amperes	Venturi Head in	Pitot Dynamic Head	Flow In Cubic Feet Per		Coefficient
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
.45	1.43	.069	.085	.114	1.342
.42	1.30	.057	.080	.104	1.31
.40	1.00	.0525	.069	.100	1.45
.36	.80	.043	.0625 -	.0903	1.44
.33	.60	.0375	.0525	.0845	1.61
.30	.55	.033	.050	.079	1.58
.25	.40	.025	.0425	.069	1.63
.20	.20	.0164	.025	.0557	2.225
.10	0	0	0	0	
.8					

Ave Coef = 1.353

Short circuit voltage rose from 37.5 to 38.5 and amperes from .97 to .99 during this run.

Table VI.

Amperes	Venturi Head in Inches of Mercury	Pitot Dynamic Head in Inches of Mercury	Flow In Cubic Feet Per Second From Venturi	Flow In Cubic Feet Per Second From Pitot	Coefficient	Amperes	Venturi Head in Inches of Mercury	Pitot Dynamic Head in Inches of Mercury	Flow In Cubic Feet Per Second From Venturi	Flow In Cubic Feet Per Second From Pitot	Coefficient
0	0	0	0	0		.84	4.40	.205	.1445	.197	1.36[illegible]
.1	.20	.0082	.025	.0395	1.58	.82	4.30	.197	.1425	.194	1.3[illegible]
.2	.35	.0164	.038	.0557	1.465	.79	4.10	.187	.139	.188	1.352
.25	.55	.025	.050	.069	1.38	.74	3.95	.168	.137	.1875	1.36[illegible]
.30	.80	.033	.0625	.079	1.262	.72	3.65	.160	.132	.1745	1.32[illegible]
.33	1.000	.0375	.069	.0845	1.22	.69	3.30	.150	.125	.168	1.34
.36	1.10	.043	.0745	.0903	1.21	.65	3.05	.131	.123	.158	1.305
.40	1.25	.0525	.0785	.100	1.272	.62	2.80	.123	.116	.153	1.3[illegible]
.42	1.50	.057	.0865	.104	1.205	.60	2.70	.1175	.114	.149	1.305
.45	1.75	.069	.090	.114	1.265	.58	2.55	.1105	.111	.1445	1.30
[illegible]	1.90	.0785	.0965	.122	1.262	.56	2.15	.103	.1015	.140	1.38
.51	2.10	.085	.100	.127	1.27	.53	1.95	.092	.0975	.132	1.35[illegible]
.53	2.20	.092	.1025	.132	1.285	.51	1.80	.085	.09[illegible]	.127	1.33[illegible]
.56	2.50	.103	.112	.140	1.272	.48	1.60	.0785	.090	.122	1.37
.58	2.75	.1105	.115	.1445	1.255	.45	1.43	.069	.085	.114	1.31[illegible]
.60	2.90	.1175	.118	.149	1.26	.42	1.30	.057	.080	.104	1.31
.62	3.10	.123	.122	.153	1.255	.40	1.00	.0525	.069	.100	1.1[illegible]
.65	3.40	.131	.1275	.158	1.24	.36	.80	.043	.0625	.0903	1.44
.69	3.60	.150	.131	.168	1.281	.33	.60	.0375	.0525	.0845	1.61
.72	3.85	.160	.135	.1745	1.292	.30	.55	.033	.050	.079	1.58
.74	4.00	.168	.138	.1785	1.292	.25	.40	.025	.0425	.069	1.[illegible]3
.79	4.40	.187	.3445	.188	1.30	.20	.20	.0164	.025	.0557	2.225
.82	4.60	.197	.1475	.194	1.315	.10	0	0	0	0	
.84	4.70	.205	.149	.197	1.32						
.89	5.10	.258	.155	.2215	1.43						
.90	6.30	.262	.1725	.223	1.29						
.92	6.45	.270	.175	.227	1.297						
.90	6.30	.262	.1725	.223	1.29						
.89	6.10	.258	.170	.2215	1.305						
.86	4.65	.213	.1585	.201	1.265						

Ave. Coef. = 1.353

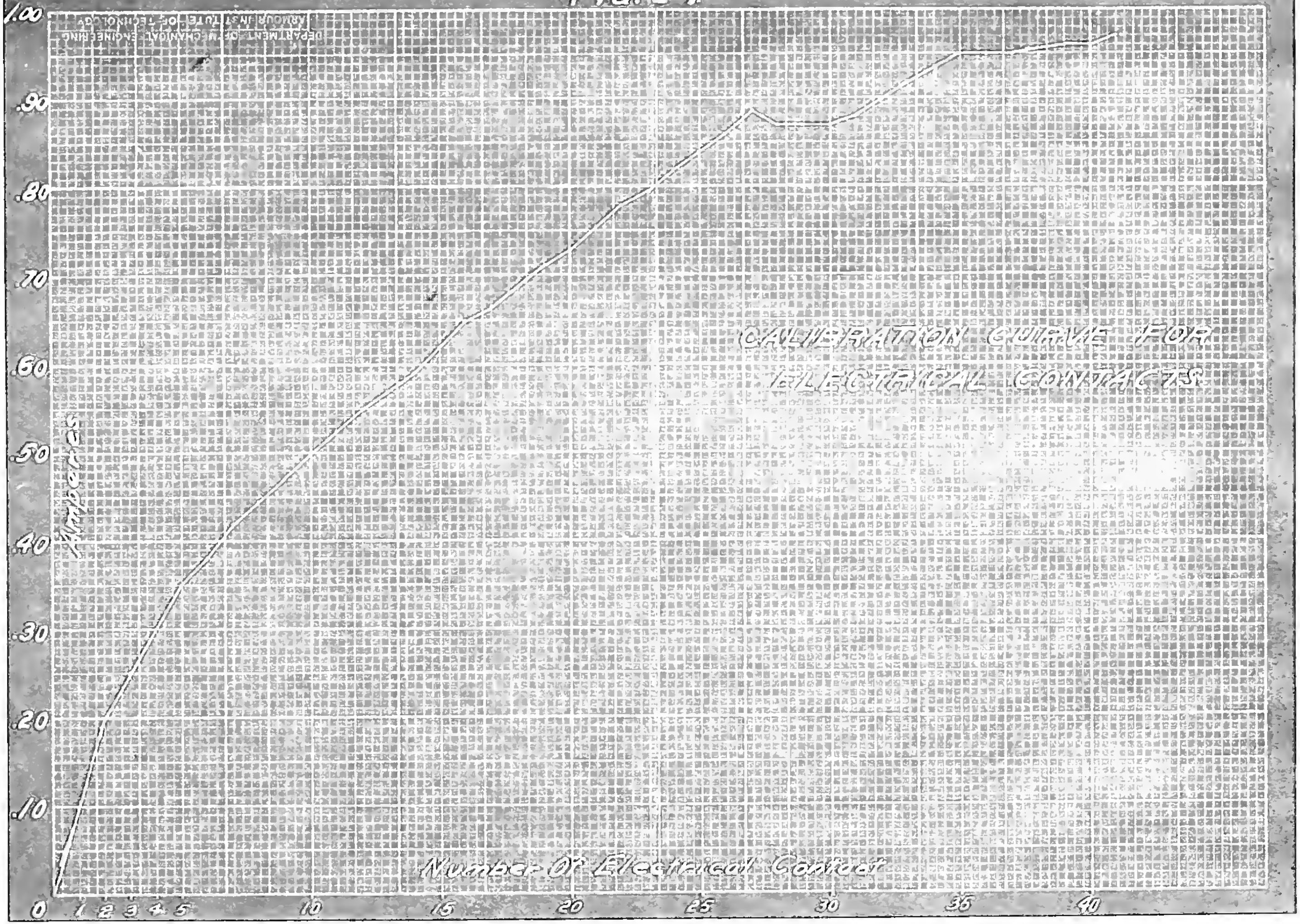
Short circuit voltage rose from 37.5 to 38.5 and amperes from .97 to .99 during this run.

Amperes	Venturi Head in Inches of Water	Pitot Dynamic Head in Inches of Water	Flow In Cubic Feet Per Second From Venturi	Flow In Cubic Feet Per Second From Pitot	Coefficient	Amperes	Venturi Head in Inches	Pitot Dynamic Head In	Flow In Cubic Feet Per Second	Flo...
50	1.80	.083	.095	.1247	1.315					
55	2.30	.090	.105	.131	1.25					
59	2.70	.115	.114	.1478	1.30					
66	3.35	.1375	.126	.162	1.285					
73	4.00	.164	.1375	.1763	1.28					
78	4.20	.180	.141	.185	1.31					
83	4.80	.199	.151	.1942	1.285					
86	5.85	.213	.1665	.2015	1.21					
.88	6.10	.254	.170	.219	1.285					
.89	6.60	.258	.177	.2215	1.252					
.92	7.50	.270	.189	.2265	1.20					
.89	7.00	.258	.1825	.2215	1.215					
.88	6.25	.254	.1575	.219	1.39					
.86	5.15	.213	.156	.2015	1.29					
.83	5.00	.199	.154	.1942	1.26					
.78	4.65	.180	.148	.185	1.252					

Table VII.

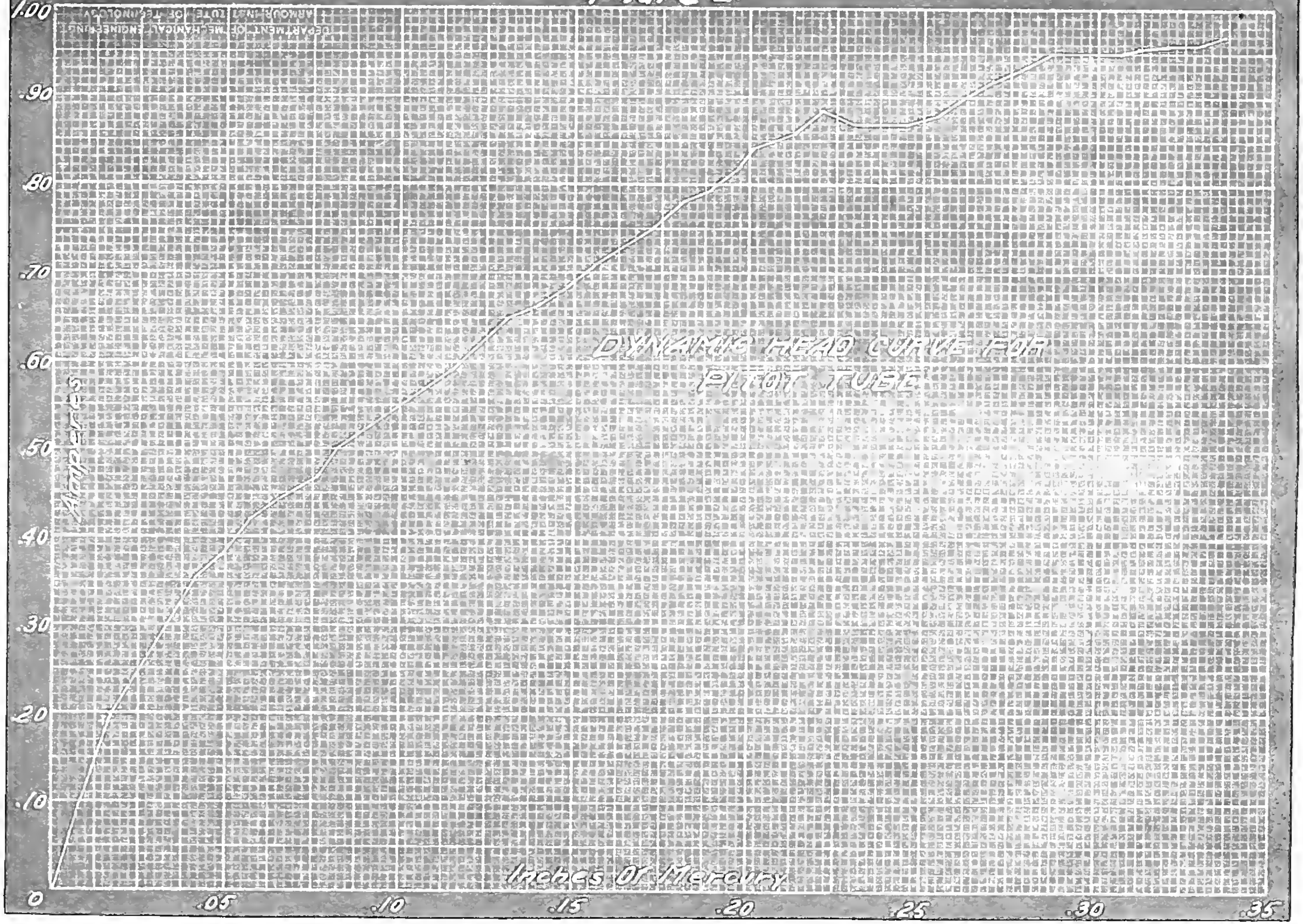
Amperes	Venturi Head in Inches of Mercury	Pitot Dynamic Head in Inches of Mercury	Flow In Cubic Feet Per Second From Venturi	Flow In Cubic Feet Per Second From Pitot	Coefficient	Amperes	Venturi Head in Inches of Mercury	Pitot Dynamic Head in Inches of Mercury	Flow In Cubic Feet Per Second From Venturi	Flow In Cubic Feet Per Second From Pitot	Coefficient
[illegible]	0	0	0	0		.45	1.16	.069	.0835	.114	1.365
.10	.21	.0062	.025	.0395	1.58	.39	1.00	.051	.069	.0983	1.425
[illegible]	.35	.0164	.0375	.0557	1.482	.35	.90	.041	.0635	[illegible]	1.32
.25	.70	.025	.0525	.069	1.315	.30	.70	.033	.0575	.079	1.37
[illegible]	.80	.033	.0625	.079	1.265	.25	.40	.025	.0125	[illegible]	1.62
.35	1.00	.041	.060	.088	1.27[illegible]	.20	.30	.0164	.034	[illegible]	1.635
[illegible]	1.20	.051	.0775	.0983	1.270	.10	.15	.0082	[illegible]	.0395	1.80
.45	1.35	.069	.090	.114	1.270	.0	0	0	0	0	
.50	[illegible].10	.082	.100	.1247	1.247						
.55	2.50	.090	.110	.131	1.192		Ave.	coef.	=	1.36	
[illegible]	3.00	.115	.1195	.1478	1.235						
[illegible]	3.60	.1405	.131	.1665	1.27						
[illegible]	[illegible]	.164	.141	[illegible]	1.25						
[illegible]	[illegible]	.180	.148	.185	[illegible]						
[illegible]	[illegible]	.199	.154	.1942	[illegible]						
[illegible]	5.15	.217	.156	.2015	1.29						
[illegible]	[illegible]	.254	.1575	.219	1.39						
[illegible]	7.00	.258	.1825	.2215	1.215						
[illegible]	7.50	.270	.189	.2265	1.20						
[illegible]	[illegible].60	.258	.177	.2215	1.252						
[illegible]	[illegible].10	.254	.170	.219	1.285						
[illegible]	5.85	.213	.1565	.2015	1.21						
[illegible]3	4.80	.199	.151	.1942	1.285						
[illegible]78	4.20	.180	.141	.185	1.31						
[illegible]73	4.00	.164	.1375	.1763	1.28						
[illegible]66	3.35	.1375	.133	.162	1.285						
.59	2.70	.115	.114	.1478	1.30						
.55	2.30	.090	.105	.131	1.25						
.50	1.80	.083	.095	.1347	1.315						

Plate 1



CALIBRATION CURVE FOR ELECTRICAL CONTACTS
Amperes
Number Of Electrical Contact
DEPARTMENT OF MECHANICAL ENGINEERING
ARMOUR INSTITUTE OF TECHNOLOGY
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
1 2 3 4 5
10
15
20
25
30
35
40

Plate 2.



DYNAMIC HEAD CURVE FOR
PITOT TUBE
Amperes
Inches of Mercury
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
.05
.10
.15
.20
.25
.30
.35

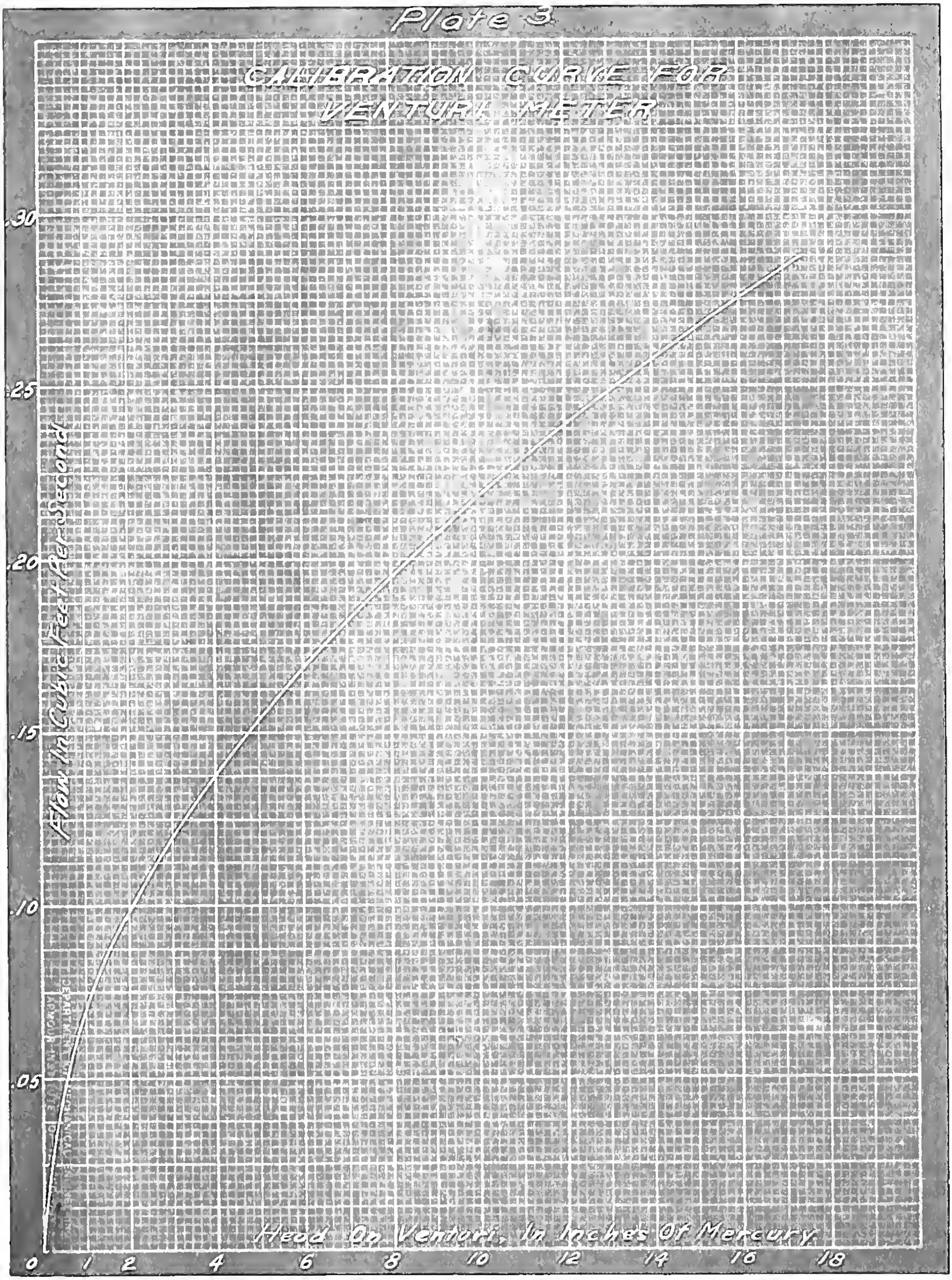
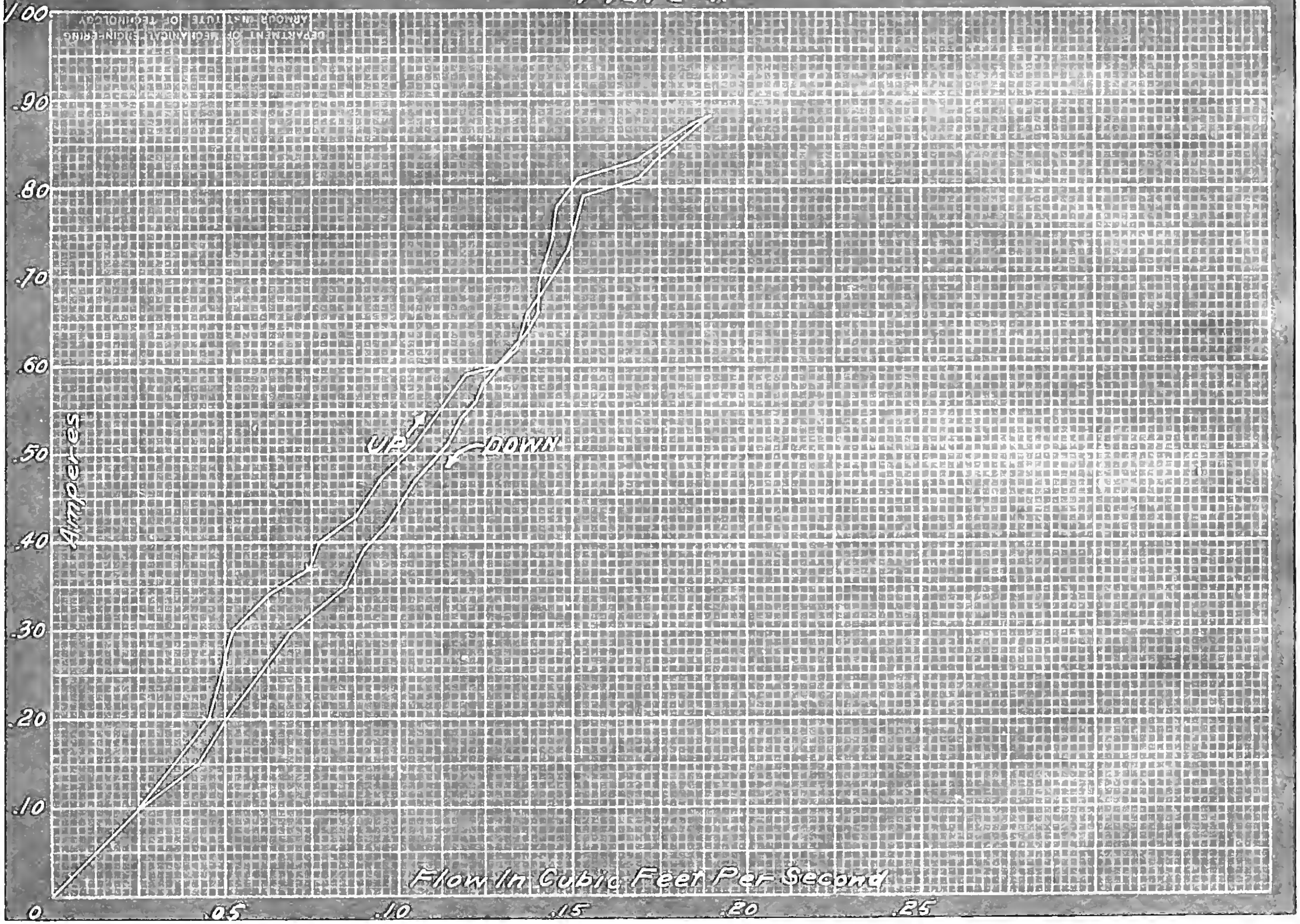


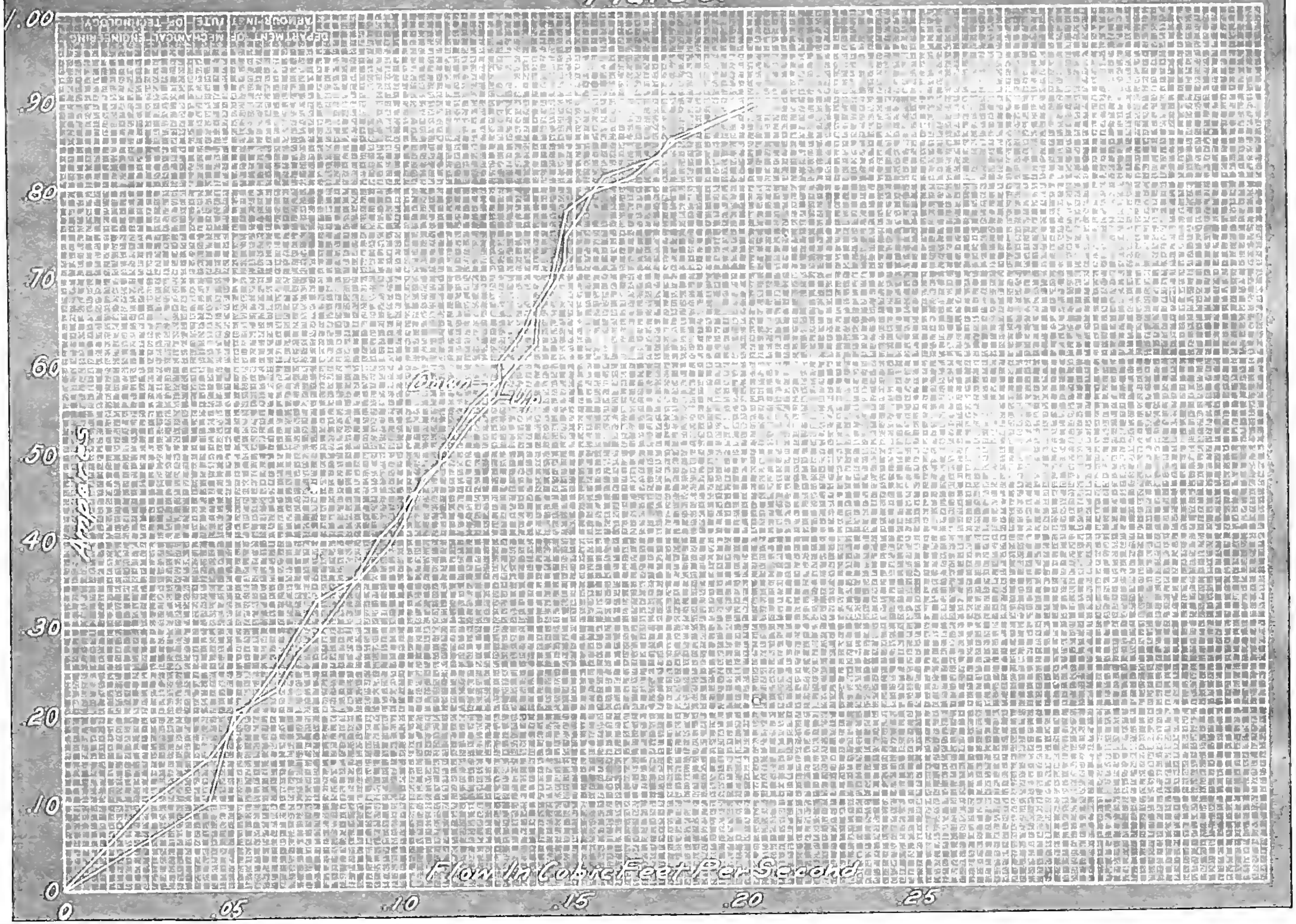
Plate 3
CALIBRATION CURVE FOR
VENTURI METER
Flow In Cubic Feet Per Second
.30
.25
.20
.15
.10
.05
Head On Venturi, In Inches Of Mercury
0
1
2
4
6
8
10
12
14
16
18

Plate 4.



DEPARTMENT OF MECHANICAL ENGINEERING
ARMOUR INSTITUTE OF TECHNOLOGY
Amperes
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
.05
.10
.15
.20
.25
UP
DOWN
Flow In Cubic Feet Per Second

Plate 5.



1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
Amperes
0
.05
.10
.15
.20
.25
Flow In Cubic Feet Per Second
Down
Up

Plate 6.

Amperes
Flow In Cubic Feet Per Second
Down
Up
0
.05
.10
.15
.20
.25
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00

Plate 7.

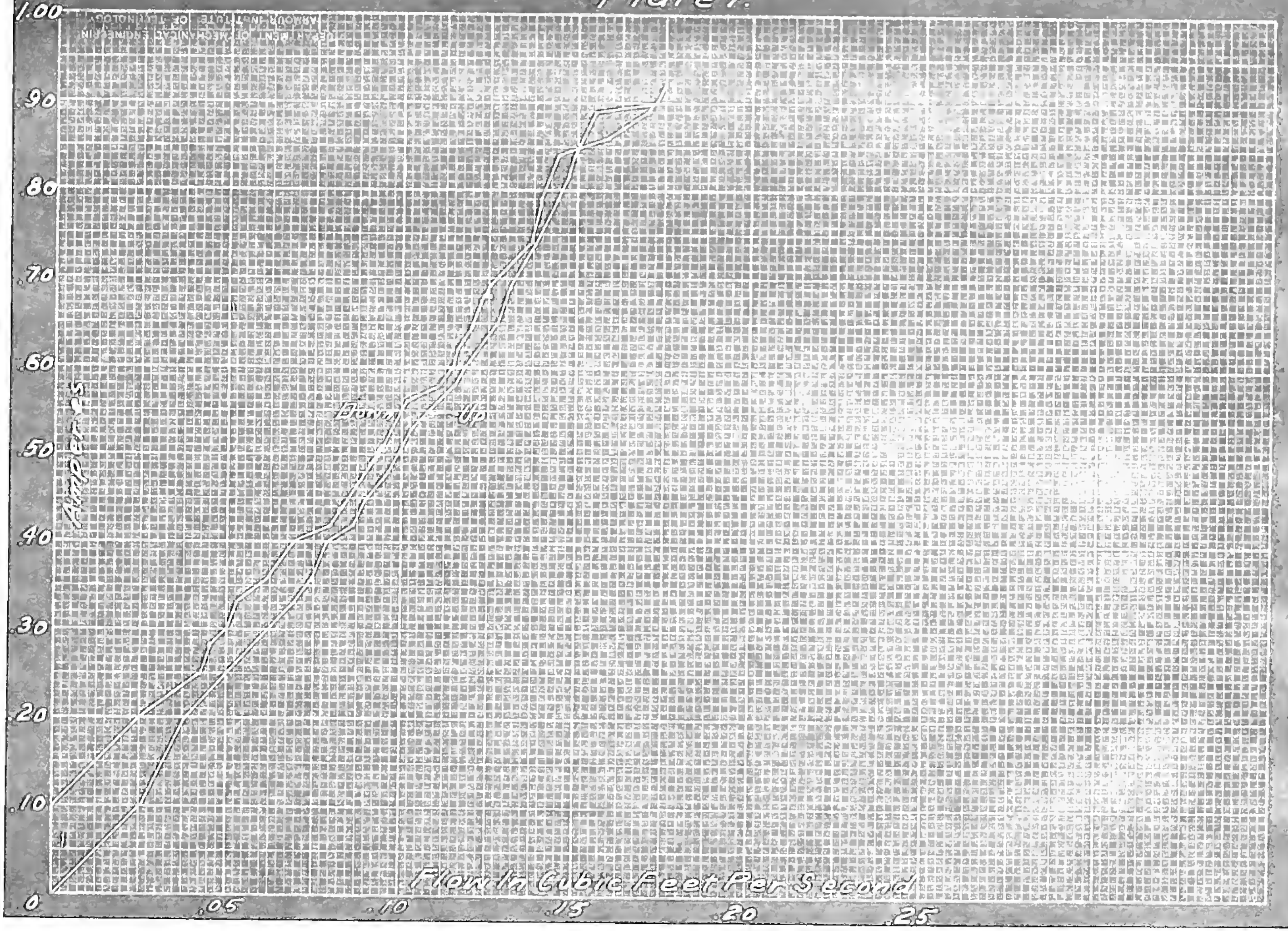

1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
.05
.10
.15
.20
.25
Amperes
Flow in Cubic Feet Per Second
Down
Up

Plate 8.

Amperes
Down
Up
Flow In Cubic Feet Per Second
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
.05
.10
.15
.20
.25

Plate 9.

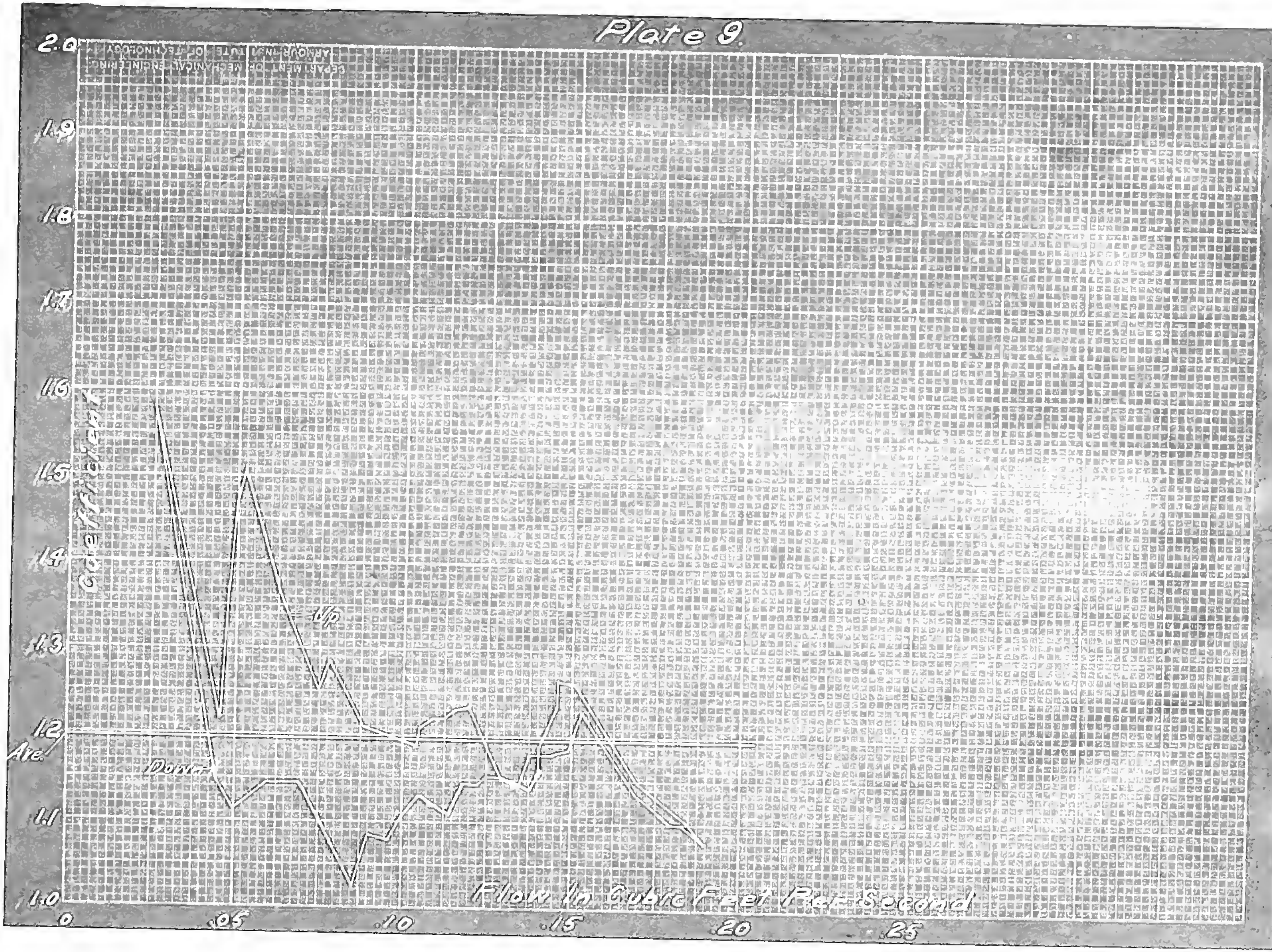
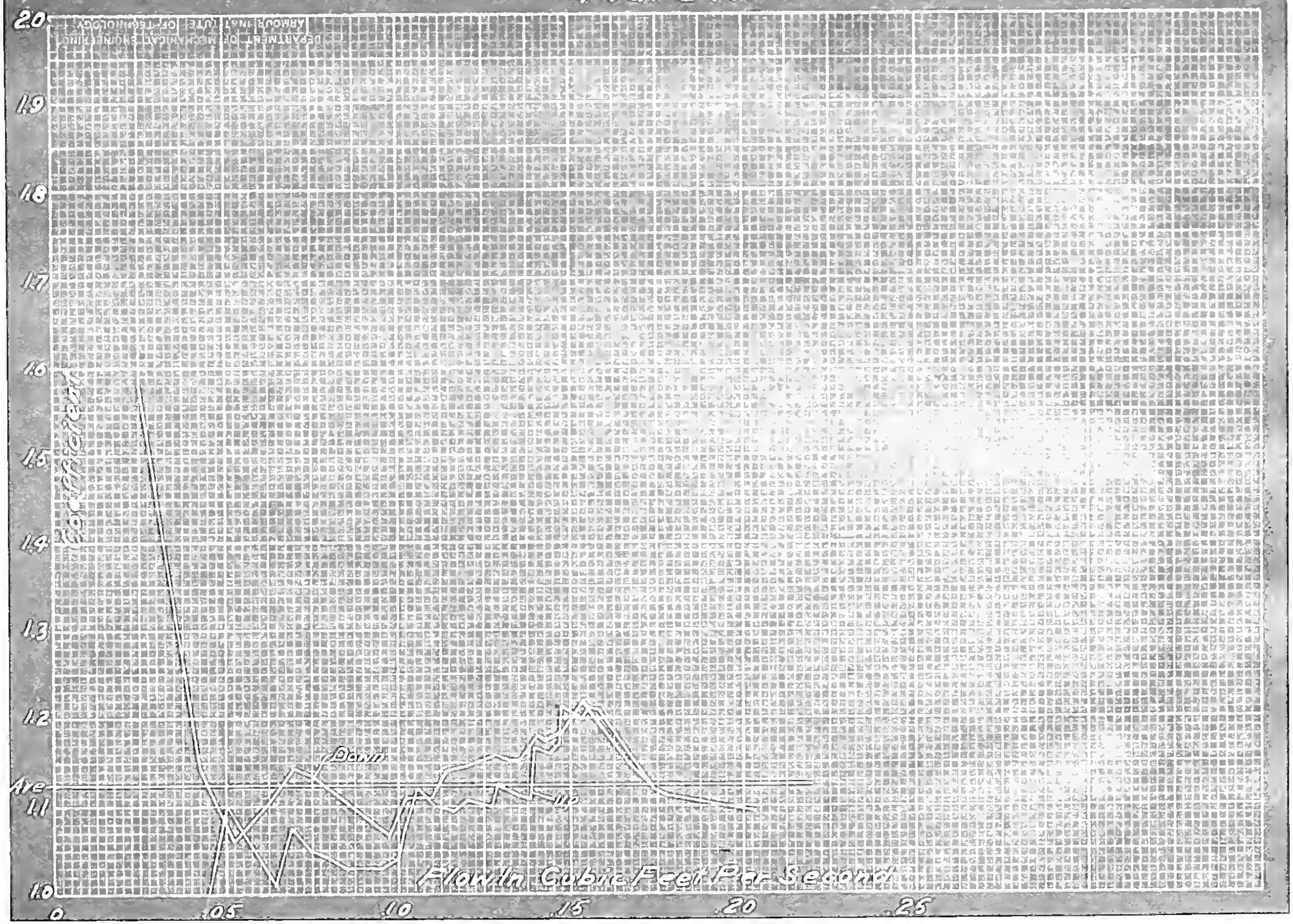
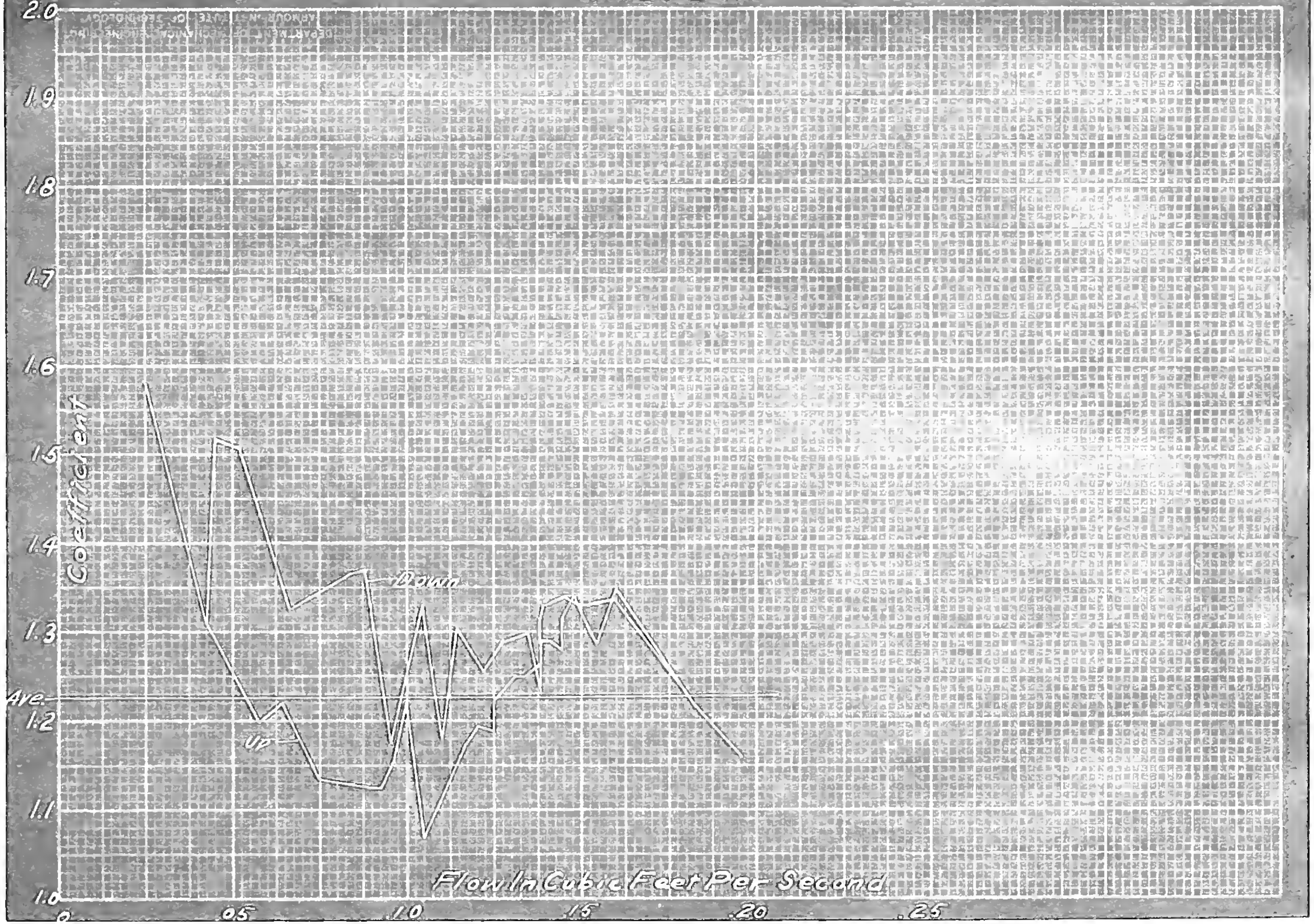

DEPARTMENT OF MECHANICAL ENGINEERING
ARMOUR INSTITUTE OF TECHNOLOGY
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
Coefficient
Ave.
Up
Down
0
.05
.10
.15
.20
.25
Flow In Cubic Feet Per Second

Plate 10.



Coefficient
Flow In Cubic Feet Per Second
Down
Up
Ave
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0
.05
.10
.15
.20
.25

Plate II.



Coefficient
Flow In Cubic Feet Per Second
Down
Up
Ave.
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0
.05
.10
.15
.20
.25

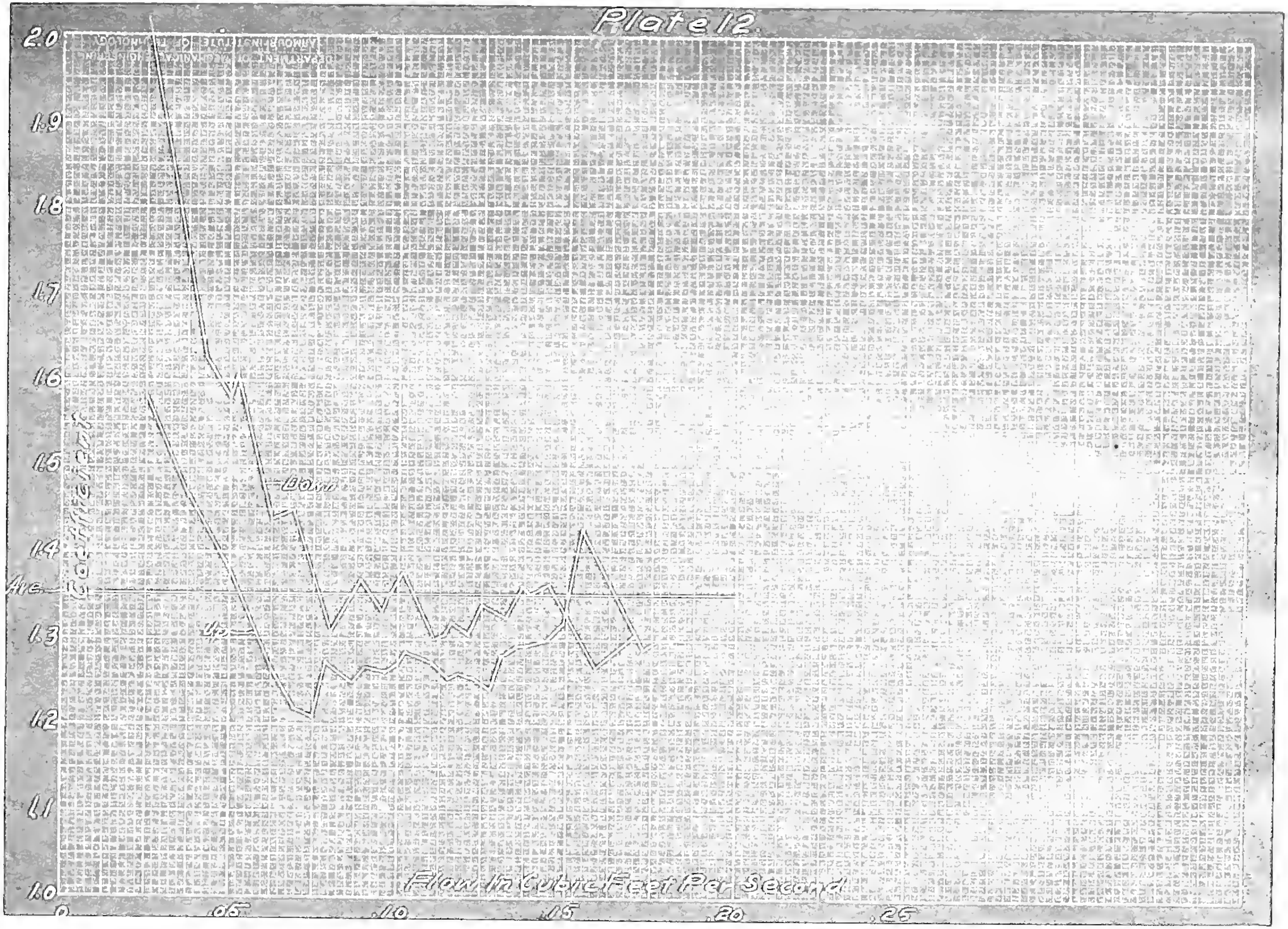
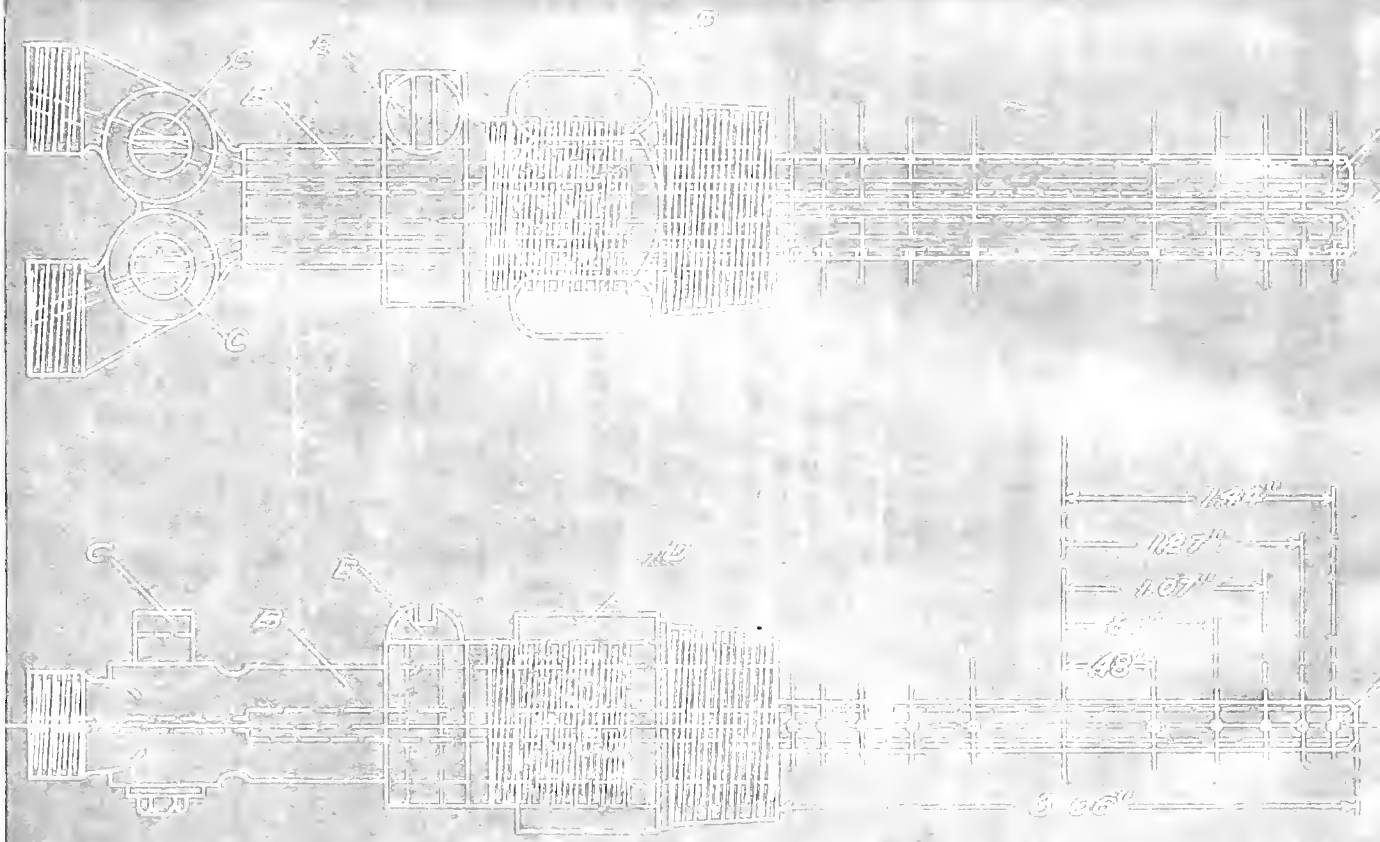


Plate 12.
Armour Institute of Technology
Department of Mechanical Engineering
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
Coefficient
Ave.
Down
Up
0
.05
.10
.15
.20
.25
Flow In Cubic Feet Per Second

Plate 13.

2.0
1.9
1.8
1.7
1.6
1.5
1.4
Ave.
1.3
1.2
1.1
1.0
0
.05
.10
.15
.20
.25
Coefficient
Down
Up
Flow In Cubic Feet Per Second

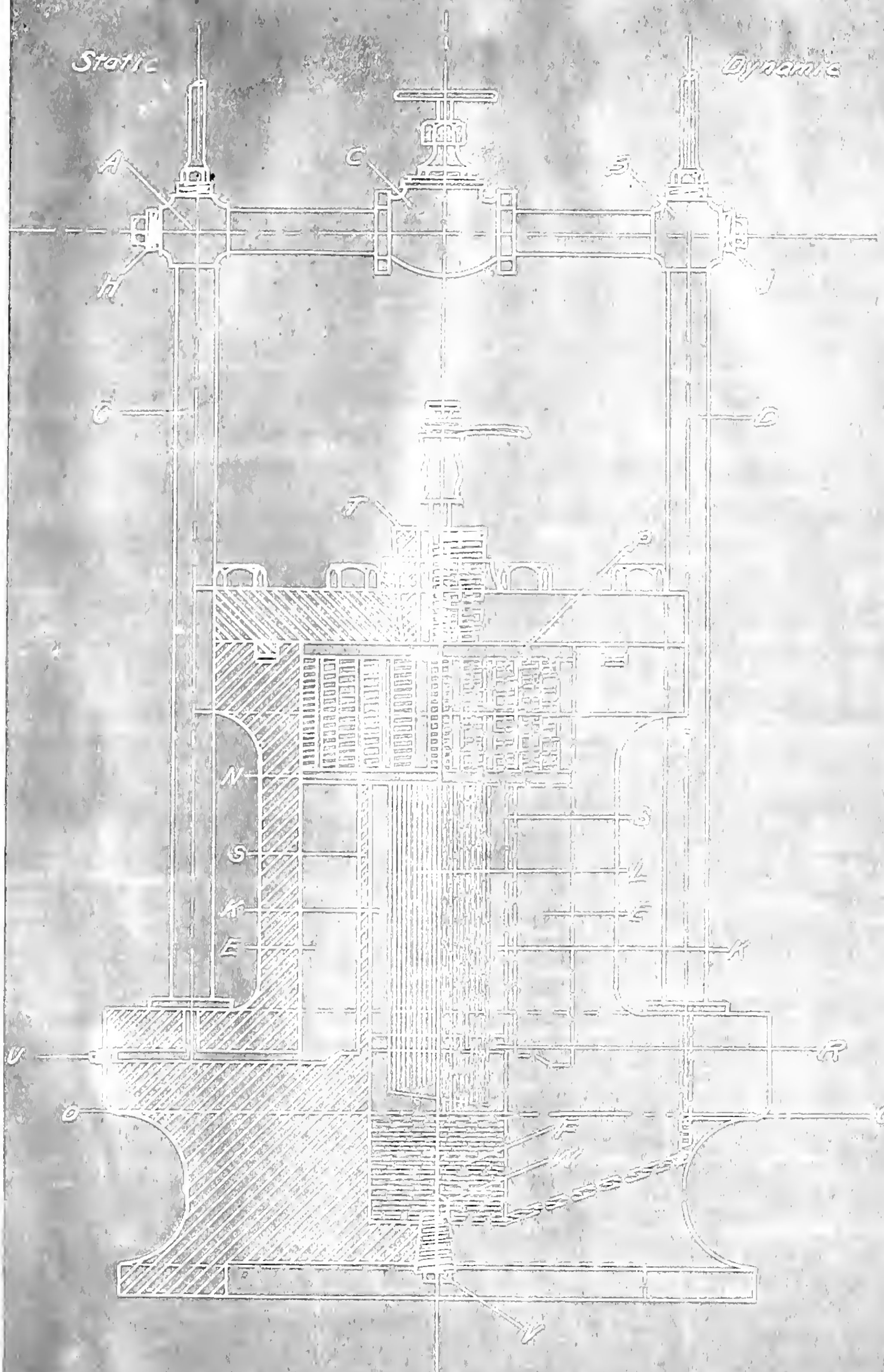
Plate 14



THE MULTIOPENING AVERAGING PITOT TUBE

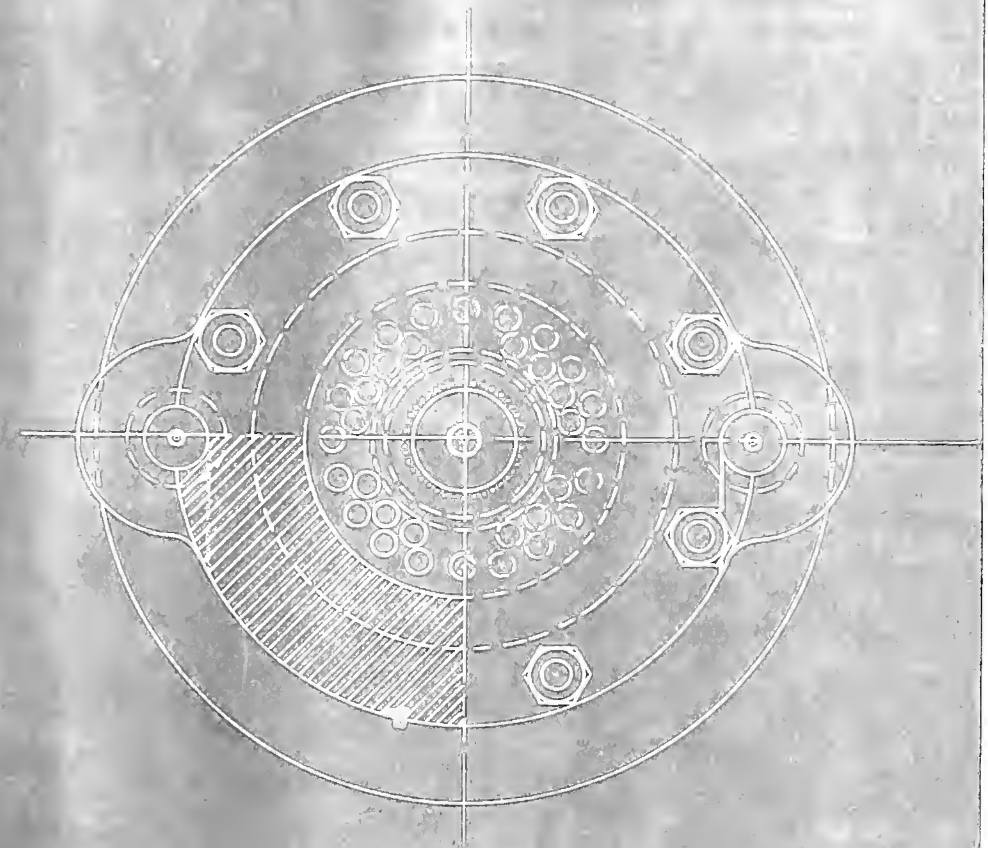
Scale—Full Size

Plate 15.



SECTION THROUGH METER
Scale - Half Size

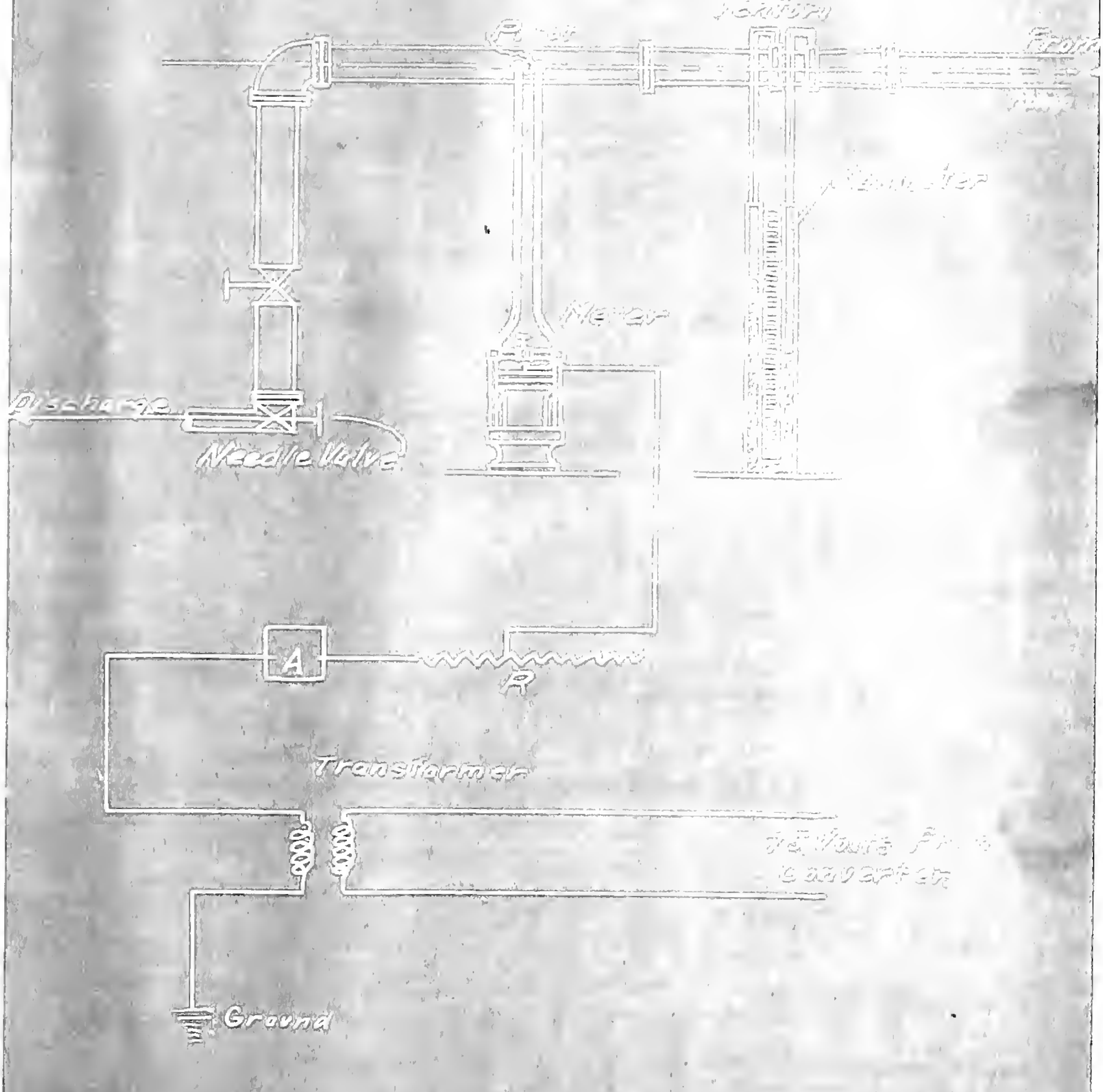
Plate 16.



SECTION THROUGH METER

Scale — Half Size

Plate 17



Scheme Of Connections For Test